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Conversion of the waste rapeseed oil by aerosol gliding arc discharge-assisted pyrolysis

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ABSTRACT

The aerosol gliding arc discharge-assisted pyrolysis was firstly proposed to convert the waste rapeseed oil. The arc motions in pure argon gas and oil mixture discharge were compared at different total flow rate. Calculated by FLUENT software, the average flow velocity distribution along the axis direction was obtained, ranging from 8 m/s at the arc initiated gap to 0.5 m/s at the exit. The distribution of gaseous products was investigated under the effect of applied voltage and pyrolysis temperature, which indicated 74% of waste oil was converted into gaseous products at applied voltage of 10 kV and pyrolysis temperature of 800 °C, respectively. Selectivity of gaseous products (CO, H_2 and C_2 hydrocarbons) exhibited different sensitivity to variation of operating conditions. Optical images were captured to record the evolution of deposited carbon on copper substrate under different temperatures, while the Raman spectroscopy implied that well-organized graphitized structure was formed at rotating gliding arc regime as well as the copper surface.

Introduction

With increasing stringent environmental specifications and continuous depletion of fossil fuels, conversion of waste to energy or materials is broadly recognized as a promising alternative to switch current energy consumption manner and alleviate the environmental stress simultaneously [1–3]. Motivated by recycling natural waste resource into high-valued materials such as biofuel, syngas, and carbon-based materials, booming investigations have been conducted in recent years [4,5]. N. Miskolczi et al. converted the plastics into light oils and gases at a pilot scale pyrolysis under different pyrolysis temperature. [6]; T. Somanathan et al., synthesized the graphene oxide by reforming the sugarcane bagasse agricultural waste under muffled atmosphere, providing a fast and effective method to generate graphene-based material [7]. Among versatile categories of waste covering from biomass waste to industrial waste [8], used cooking oil presented as a most common and promising candidate, benefitting from its inherent huge abundance, cost efficiency and CO_2-neutral features. Sourced from the large oil manufacturers and daily

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cooking, million tons of waste cooking oils was generated in China annually. However, 40–60% of the waste cooking oil from urban restaurant industry was backflow into dining tables through illegal channels. In addition, arbitrary dumping of the waste cooking oil would cause water and soil pollution, and threaten aquatic life and soil organism. Thus, recycling waste cooking oil not only lowered the cost for production of oil-derived chemicals, but also reduced the stress from food security and waste management.

Deemed as a cheap and sustainable natural donator for renewable energy and materials [2,9], hydrotreating, steam gasification and pyrolysis were developed to fabricate waste oil based chemicals including hydrogen, biodiesel, syngas, jet fuel, etc. [10–13]. For instance, A. Suriani et al. fabricated vertically aligned carbon nanotubes from waste cooking palm oil by a two-stage chemical vapor deposition reactor with floating-catalyst, and obtained bundles of a mixture of single-wall and multiwall carbon nanotubes in good field electron emission property [14]. However, conventional methods usually needed catalyst added in starting materials, with potential secondary pollution, or applied complex multi-step technologies and expensive facilities with low energy and economic efficiency. Herein, atmospheric pressure rotating gliding arc (AP-RGA) discharge combined with pyrolysis is proposed to reform the waste cooking oil thoroughly, with the benefits of sufficient energetic active species and stable temperature atmosphere. Regarded as an economical, convenient and environmentally benign method to pretreat waste rapeseed oil, RGA discharge took the advantages of synergetic effects of high vib-rotational temperatures and various active spices in plasma region [15]. Breaking down the long aliphatic chains into light products and building pieces of solid carbon took place via RGA discharge, regardless of complex fatty acids mixed in the waste oil. In addition, pyrolysis is integrated with the RGA discharge in our system by providing a controlled temperature atmosphere. The system was further improved by feeding the oil in an aerosol-phase, leading to a homogenous distribution of oil particle and stable transport during whole plasma and pyrolysis process [16].

In this article, aerosol RGA discharge-assisted pyrolysis was firstly introduced as an innovative method to recycle the waste rapeseed oil (WRO). Time-dependent arc behaviors of discharges in pure argon and oil aerosol were recorded and compared at different total flow rate injected. Numerical simulation was applied to further describe the arc dynamic motion, which was intimately intertwined with the distribution of flow field and distribution of velocity. Oil-gas conversion rate and gas yield distribution were investigated as a function of temperature and applied voltage. The solid carbon attached on the electrode was collected and analyzed by Raman spectroscopy, in order to describe the effect of plasma on carbon formation. The evolution of deposited carbon on the copper film inside the furnace was visualized with the variation of temperature. These studies were conducted to provide the preliminary understanding of operation in RGA discharge-assisted pyrolysis, and expected to pave potential route to convert waste cooking oil into syngas or useful carbon material by this interesting method.

Experiments and methods

Aerosol RGA discharge-assisted pyrolysis system

Purchased from Henan Yi Feng Oil Ltd., the virgin rapeseed oil was open heated at 270 °C with intense stirring for 120 min to simulate the cooking process in daily life. Estimated by an Elemental Analyzer (1ECO-CMNS932), the elemental composites (wt%) of the produced WRO were C (72.44%), H (11.34), N (0.04%) and O (16.18%) [2]. The oil was converted into aerosol-phase by passing through a particle generator (TSI 9302) at inner pressure of 10 psi set by an equipped pressure gauge. In our serial experiments, the flow rate of oil was set at 0.0275 g/min. The mean size of oil particle was approximately at 0.6 um measured by an aerodynamic particle sizer (TSI 3321). Argon (99.9% purity) was used as carrier gas to transport the oil aerosol and initiate arc motion, regulated by a mass flow controller (MFC, Sevenstar D07). The whole aerosol RGA discharge-assisted pyrolysis system was detailed illustrated in previous work [2]. During the experiments, the oil aerosol was introduced into our RGA reactor, which was detail illustrated in previous work [17,18]. With high voltage (Teslaman TLP 2040) applied on the electrodes, the arc was initiated at the narrowest gap (2 mm). Then the arc was spirally propelled and elongated by tangential introduced feed gas, and stabilized at certain position [19]. Co-driven by Lorentz force induced a permanent ring magnets with a flux density of approximated 2000 G, the rotation of arc was accelerated, which facilitated the efficient interaction between plasma and reagents. Stimulated by versatile active species (energetic electrons, excited molecules, ions, atoms) induced by discharge, the decomposition of oil aerosol took place in plasma regime. And subsequently the produced products were conveyed by carried gas into a quartz tube (380 mm in width and 800 mm in length), which was inserted inside a programmed furnace (LTKC-13CX). The furnace was adjusted over the temperature range of 500–800 °C with the interval of 100 °C. In the middle of the quartz tube, copper foil was provided as the substrate and catalyst in order to obtain nano-structure carbon in our experimental circumstance. All the experiments were conducted repeatedly in atmospheric pressure.

Arc motion and flow field distribution

The images of arc dynamic motions in the plasma reactor were captured by a high speed digital camera (HG-100K, CMOS sensor, 1504 × 1128 pixels) with the frame rate set at 2000 frames/s. The images were analyzed by using the Motion Central Program. In order to investigate the influence of flow field and velocity distribution on the arc behaviors, 3D model of RGA reactor was firstly built up by GAMBIT and calculated by commercial computational fluid dynamics (CFD) software FLUENT.

Products characterization

The gases generated was collected and quantitatively analyzed by a gas chromatograph (GC 9790A, Fuli Analytical Instrument) coupled with a thermal conductivity detector